

# Computational modeling of cell migration through a degradable viscoelastic extracellular matrix

Tommy Heck<sup>\*1a</sup>, Bart Smeets<sup>2</sup>, Simon Vanmaercke<sup>2</sup>, Diego A. Vargas<sup>1</sup>, Herman Ramon<sup>2</sup>, Paul van Liedekerke<sup>3</sup> and Hans van Oosterwyck<sup>1,4</sup>

<sup>1</sup>*Biomechanics Section, Department of Mechanical Engineering, KU Leuven, Belgium,*

<sup>2</sup>*MeBioS, Department of Biosystems, KU Leuven, Belgium,*

<sup>3</sup>*Institut National de Recherche en Informatique et en Automatique (INRIA), Paris, France,*

<sup>4</sup>*Prometheus, Division of Skeletal Tissue Engineering, KU Leuven, O&N 1, Belgium*

## Abstract.

### *Introduction*

Cell migration is vital for many processes in the human body like tissue development, tissue regeneration and angiogenesis. Cells adhere to the extracellular matrix (ECM), generate protrusive and contractile forces and degrade the ECM in order to move through. Therefore, the ECM is an important regulator of cell migration. In order to get a better understanding of the role of the ECM in cell migration, we have developed a computational model of cell migration through the ECM by local ECM degradation.

### *Methods*

A 2D computational model has been developed coupling a mechanical deformable cell model to a model describing the viscoelastic behavior and degradation of the ECM. The ECM is modelled by a method called non-inertial smoothed particle hydrodynamics (NSPH) [1]. This is a mesh-free numerical method in which, by discrete convolution with a smoothing kernel, the continuum laws of fluid and solid mechanics are implemented in a discrete way. The mesh-free character allows to simulate large deformations of the ECM and to simulate the migration of a cell through the ECM without the need of computationally expensive remeshing. The cell is modelled by a set of NSPH particles connected by line segments that capture the mechanical properties (viscoelasticity and bending rigidity) of the actin cortex as implemented before in [2]. This cell model is embedded in the ECM model. A boundary correction is applied for NSPH particles of the ECM in contact with the cell model in order to ensure correct contact mechanics between the cell and the ECM. Filopodia that apply contractile forces leading to cell migration are modelled as springs that are initially positioned in a stretched state and are attached both to a particle of the cell model and to particles of the ECM. Degradation of the ECM by the cell is modelled by local relaxation of the deviatoric stress, resulting in a fluidized material that can be pushed aside by the cell in order to move through the ECM. Altogether, this results in a model of cell migration through a viscoelastic ECM.

### *Results and discussion*

Various simulations have been performed to validate viscoelastic NSPH with an extended boundary correction as a new method to model the ECM. The potential of this method to capture cell-ECM interactions has been demonstrated first by the migration of a rigid circular cell model through the ECM by local degradation. Next, spreading of a deformable cell in an ECM (see Fig. 1) has been modelled and compared with results from traction force microscopy. Finally, migration of a deformable cell model by contractile filopodia forces and local degradation has been simulated. This model will be used to investigate the effect of mechanical ECM properties, degradation and filopodia dynamics on cell

---

\*Corresponding author, Ph.D Student, E-mail: [tommy.heck@kuleuven.be](mailto:tommy.heck@kuleuven.be)

migration. Altogether, data suggest that our coupled cell-ECM model can capture important features of single cell migration and cell-matrix interaction. By validation with and feedback to experiments, this model can therefore aid in unravelling the mechanisms behind cell-matrix interaction.

**Keywords:** smoothed particle hydrodynamics, deformable cell model, cell migration, viscoelastic extracellular matrix, degradation

---

## References

- [1] Van Liedekerke, P et al. (2013), “Solving microscopic flow problems using Stokes equations in SPH”, *Computer Physics Communications*, **184**(7), 1686-1696.
- [2] Odenthal T. et al. (2013), “Analysis of initial cell spreading using mechanistic contact formulations for a deformable cell model”, *PLoS Computational Biology*, **9**(10), e1003267.

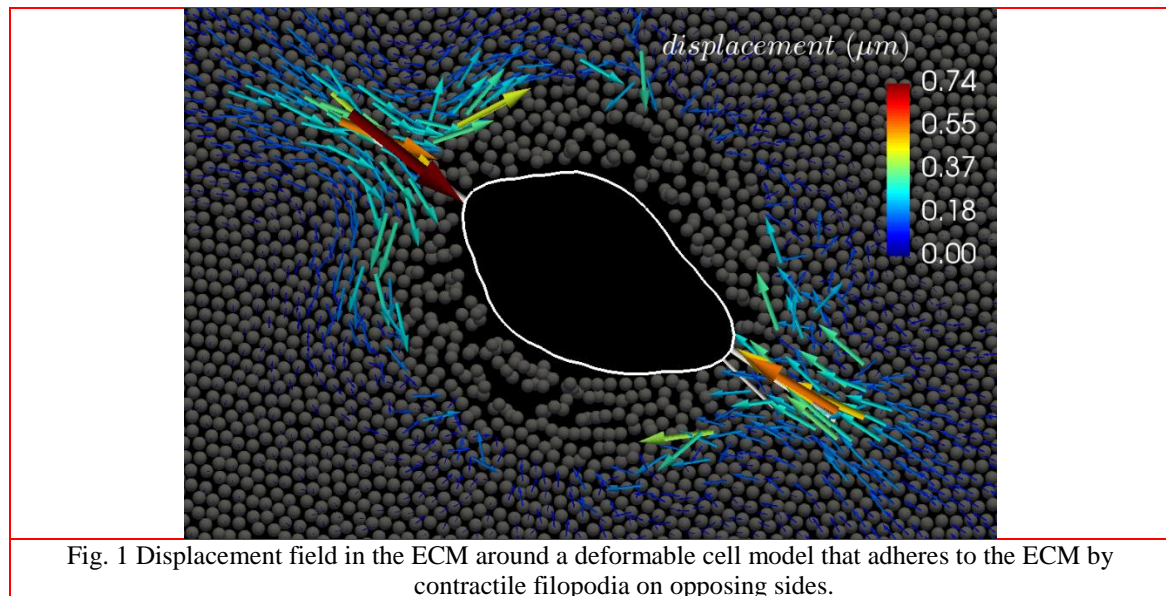


Fig. 1 Displacement field in the ECM around a deformable cell model that adheres to the ECM by contractile filopodia on opposing sides.